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**RADIO FREQUENCY INTERFERENCE
EXPERIMENT DESIGN FOR THE
APPLICATIONS TECHNOLOGY SATELLITE**

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

In implementing operational communications satellite systems and planning for advanced systems with optimum utilization of the frequency spectrum, a need has arisen for data on mutual RF interference between satellite and terrestrial telecommunications systems. The National Aeronautics and Space Administration has undertaken the design of experiments to provide such data.

The proposed experiment described herein is designed to measure and evaluate the amount of mutual interference between communications-satellite and terrestrial microwave relay systems at the shared common carrier frequency bands of 6 and 4 GHz. It is proposed to measure terrestrial-to-satellite interference at 6 GHz and satellite-to-terrestrial interference at 4 GHz. To meet the technical requirements of this experiment, it is necessary to utilize a satellite of the type planned for the ATS F and G program. These spacecraft, each carrying a 30-foot parabola as the prime antenna, will be capable of 0.1-degree pointing accuracy and full earth-scanning coverage. Measurements will be made of several parameters to obtain a fuller understanding of existing conditions related to such interference. Parametric measurements will include transmitted and received power levels, propagation-path loss and variations as a function of range, elevation angle, RF polarization, and geographical location of interference sources. Sufficient statistical information can be accumulated to establish criteria for sharing the presently available 500-MHz frequency bands.

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INTRODUCTION

The need for experimental data on mutual RF interference between satellite and terrestrial telecommunications systems stems from two recent developments. First, recommendations of the International Telecommunication Union (ITU) on space frequency allocations and frequency spectrum sharing contain criteria developed for global systems involving a relatively few, widely separated earth terminals: It is not certain that these criteria will suffice for the proposed U. S. domestic TV systems. Second, technical proposals which have been submitted to the Federal Communications Commission for domestic satellite communications systems are predicated on the further sharing of frequencies in the 6- and 4-GHz bands which are already allocated to the global satellite system and existing terrestrial radio relay systems on a shared basis.

The Director of Telecommunications Management (DTM), recognizing a need for additional technical data upon which to base fundamental decisions concerning proposed domestic satellite systems, requested the National Aeronautics and Space Administration to undertake the design of an experimental program to provide desired data on interference potentialities. The Radio Frequency Interference (RFI) Experiment described herein is concerned only with the mutual interference between satellites and terrestrial stations of radio relay systems.

The available technical information on satellite interference consists almost exclusively of theoretical "worst case" calculations plus limited measurements on terrestrial microwave systems (Reference 1). Decisions on frequency utilization should be based on substantive data concerning the probability of interference between systems sharing the same frequency bands.

For any given type of communications system, the noise power per channel at the receiver baseband output due to external sources is directly related to the noise power at the receiver input, and is dependent on the following system parameters (Reference 3):

- a) The number of interfering signals.
- b) Relative amplitude of interfering signal.
- c) Modulation bandwidth of desired signal.
- d) Specific baseband frequency of desired signal.
- e) Separation between desired and interfering signals.
- f) Noise power spectrum of desired signal.
- g) Noise power spectrum of interfering signal.

These parameters are commonly lumped into a single factor B, defined as the interference reduction factor of the system, (sometimes called the "receiver transfer factor").

The factor B can be calculated using the following formula:

$$B = 10 \log_{10} \frac{809 \times f_d^2 \times p \times F \times \exp(f_m^2 / 2F^2)}{f_m^2}$$

where

- f_m = top baseband frequency in MHz
- f_d = rms test tone deviation of the top channel in MHz
- F = rms multichannel deviation in MHz
- p = pre-emphasis factor for the top channel of the satellite system.

For typical current satellite system designs, B has the following values:

Number of channels in the satellite system	B in dB
Up to 240	33.5
300	32.4
600	29.7
1200	28.0

B may also be expressed in terms of the signal-to-noise ratio at baseband and the wanted to unwanted carrier ratio at the input to the receiver as follows:

$$B = 10 \log_{10} \frac{S}{I} - 10 \log_{10} \frac{C}{X}$$

where

- $\frac{S}{I}$ = signal to interference power ratio in a 4-kHz channel
- $\frac{C}{X}$ = wanted-signal to interference carrier power ratio

This relationship suggests an alternative method for evaluating the interference—namely, measuring the carrier-to-noise power ratio in the receiver. This will be the primary measurement technique in this experiment and is described in detail in the following sections.

Phase I – Uplink Interference

The technical objectives of the uplink interference tests and measurements are:

- a) Determine the integrated interference power from all 6-GHz terrestrial sources sharing the common carrier band within the RF field of view of the ATS F satellite;
- b) Establish practical G/T (receiver antenna gain/noise temperature ratio) limits for satellites sharing the 6-GHz common carrier band;
- c) Determine the geographical and frequency distribution of 6-GHz terrestrial sources sharing the common carrier band;
- d) Establish a protection ratio—wanted to unwanted carrier power (C/X)—at the satellite receiver.

The uplink tests (Figure 2) are designed to measure and identify the RF carriers of ground transmitters radiating in the 6-GHz band which are potentially capable of interfering with uplink transmission. These tests represent the only realistic method of determining the integrated interference power generated in the large geographic area that can be seen by a satellite. Because of potential uplink interference, there will be a practical lower limit to earth station radiated power. This limit can be established by using the results of the uplink tests to determine total interference power or to determine the distribution of interference power with geographic location. This will be done to the accuracy permitted by the satellite antenna pattern and pointing. Location information will be of use in the event of unexpected sources of interference. It may also be useful in designing future satellite systems, since parameters can be based on interference levels in the particular geographic areas in question.

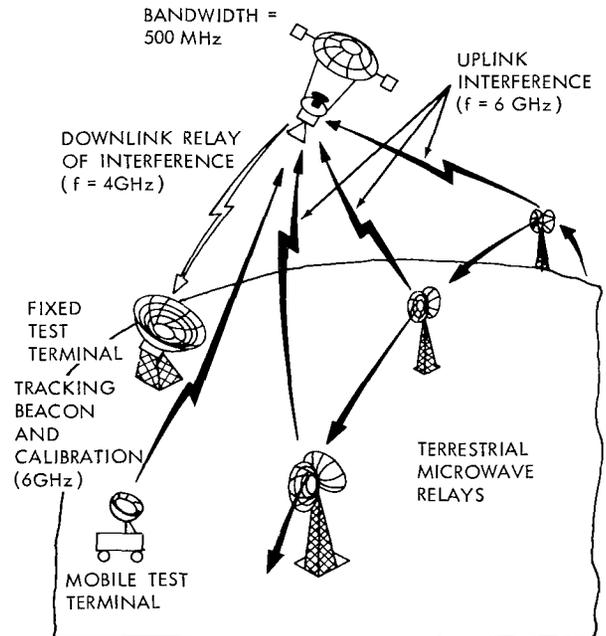


Figure 2—Uplink test configuration.

System Description

The RFI measurement system should be capable of examining uplink interference over the entire shared frequency band of 500 MHz. This requires that the satellite have either a 500-MHz

repeater bandwidth or a scanning receiver capable of sweeping across the 500-MHz band. If the system link is basically uplink-limited, as it is here, then narrowband filtering in the satellite offers no improvement in performance. Furthermore, satellite repeater simplicity is maintained with the narrowband filtering at the ground terminal.

The required ground terminal receiver will be a scanning receiver of the type used in spectrum analyzers or radio noise meters. The bandwidth is determined by the spectral width of the signals in question. The 6-GHz interference signals of interest here are RF carriers of microwave relay stations. Since the carriers are not ideal spectral lines but extend over several voice channels, a practical receiver bandwidth of 10 kHz has been chosen. Assuming a carrier-to-noise ratio of 10 dB for 10-kHz bandwidth, the required carrier-to-noise power density (C/N_0) in the satellite receiver is 50 dB(Hz).

The satellite transponder proposed for this experiment consists of a 6- to 4-GHz linear repeater which operates over a bandwidth of 500 MHz. The interference vulnerability of a satellite is determined primarily by its receiver sensitivity, which may be specified in terms of its receiver antenna gain/noise temperature ratio (G/T). The G/T for the ATS F satellite is 21 dB/°K, which requires an interference EIRP from an earth source of 5 dBw to satisfy the C/N_0 requirement of the satellite (Figure 3). Thus the satellite can detect interference signals from the earth with an EIRP as small as 5 dBw.

Considering the satellite EIRP with no signal input, the noise output EIRP should be significantly lower than the peak signal EIRP to prevent saturation of the transmitter, but it must be high enough to keep the overall system uplink-limited. For ATS F the peak EIRP is 48 dBw, and the rms noise EIRP is chosen to be 8 dB below saturation. This will allow as many as five terrestrial relay stations to radiate directly into the main beam of the satellite without saturating the transponder.

Another consideration is the time required for the ground receiver to search through the 500-MHz satellite communication band. Since the response time of a filter of bandwidth B is about $1/B$ seconds, the maximum sweep rate for such a filter is about B^2 Hz/sec. The time to sweep the desired RF band is B_{rf}/B^2 . For $B_{rf} = 500$ MHz and $B = 10$ kHz, the required time is 5 seconds.

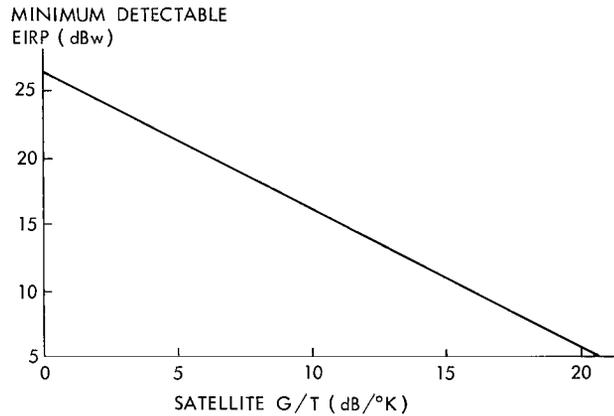


Figure 3—Uplink interference measurement sensitivity.

Ground Terminal Requirements

To evaluate the satellite ground terminal sensitivity required, two criteria may be used:

- 1) Expected EIRP from the sidelobes of typical 6-GHz radio-relay stations.
- 2) Minimum EIRP that could conceivably interfere with future earth-terminal transmissions.

Transmissions from small satellite earth terminals will be especially susceptible to interference at the satellite receiver. A small terminal may use a 10-foot dish and a 100-watt transmitter, corresponding to an EIRP of 63 dBw. The maximum protection ratio likely to be required in practice for FM systems of 10 or more channels is 34 dB, (Reference 4). The total allowable interfering EIRP from many signals would therefore be 29 dBw.

It can be concluded, therefore, that a conventional scanning receiver with 10-kHz predetection bandwidth, operating at 5 seconds per scan, will detect interference sources that are significant from the standpoint of satellite communications. However, if it is desired to detect uplink interference from individual radio-relay terminals, postdetection integration will be required, leading to scan times of several hours.

Location of Uplink Interference Sources

By recording data as the satellite receiving antenna beam is scanned over the earth's surface, it will be possible to determine the location of interference sources. The accuracy of this process should be of the order of one-quarter beamwidth or about 0.1 degree as seen from the satellite. For ground locations near the satellite longitude, this corresponds to a distance of about 50 miles in the east-west direction and about 70 miles in the north-south direction.

Phase II – Downlink Interference

The technical objectives of the downlink interference tests and measurements are:

- a) Measure interference at terrestrial terminal receivers at 4 GHz as a function of EIRP from the ATS F satellite.
- b) Using a maximum allowable EIRP determined in a), measure interference at the terrestrial terminal as a function of elevation angle.
- c) Determine the effects of atmospheric and other anomalies on interference at terrestrial terminals.
- d) Determine a practical protection ratio—wanted to unwanted carrier power (C/X)—at the terrestrial terminal receiver.

Interference from satellites to 4-GHz radio-relay links has been studied by CCIR, and a recommendation on satellite effective radiated power has been adopted (Reference 5). This recommendation ensures that, even if a satellite illuminates the main beam of a typical high-capacity

terminal, it will not produce more than 1000 picowatts of noise in an individual telephone channel. The recommendation also takes account of the angle of arrival, relative to horizontal, of the energy received at the ground.

From Figure 4 it can be seen that a satellite with 50 dBw EIRP will exceed the CCIR power density limit for all bandwidths below about 30 MHz. The density achievable in a 4-kHz bandwidth is about 40 dB above the CCIR limit. Thus, a 48-dBw capability at the satellite will permit a variety of tests to be conducted.

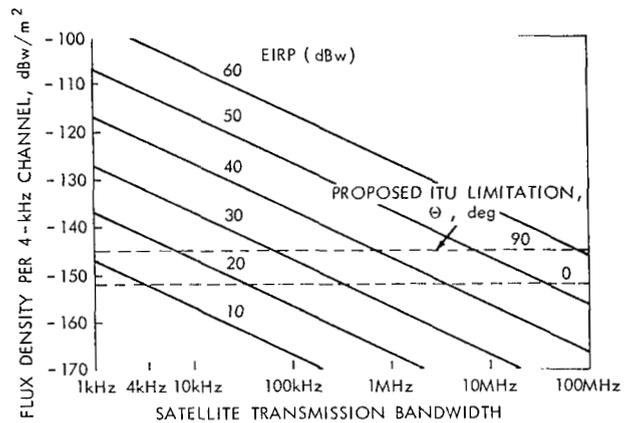


Figure 4—Flux density per 4-kHz channel vs satellite transmission bandwidth.

EXPERIMENT PARAMETERS

The determination of whether interference will occur between the terrestrial and satellite communications systems depends on the following factors:

- a) The maximum allowable value of interference power either in a telephone or in a television channel at the output of the system subject to interference;
- b) The number of specific interference paths among which the total allowable interference must be divided;
- c) The transfer function of the receivers involved;
- d) The power spectral density of the interfering signals;
- e) The transmission loss along the unwanted signal propagation path, including effective antenna gain, basic transmission (free-space) loss, and the effect of RF polarizations concerned;
- f) The power spectral density of the wanted signals; and
- g) The transmission loss along the wanted propagation path, including effective antenna gain and basic transmission loss.

Parametric Measurements Required

The specific measurements required to determine the critical parameters in this experiment include:

- a) Terrestrial (interfering) station transmitter power density output (dBw/Hz);
- b) Terrestrial station antenna polarization and gain in the direction of the satellite (dB);
- c) Satellite antenna polarization and gain in the direction of the terrestrial station (dB);
- d) Satellite transmission line losses (dB);

- e) Satellite receiver noise temperature density (dB°K/Hz);
- f) Satellite receiver transfer function (dB);
- g) Satellite transmitter power density output (dBw/Hz);
- h) Satellite transmit antenna gain in the direction of the earth terminal, or in the direction of the interfered-with terrestrial station (in the case of downlink interference) (dB);
- i) Earth terminal antenna gain (4 GHz) in the direction of the satellite (dB);
- j) Earth terminal receiver noise temperature density (dB°K/Hz);
- k) Earth terminal receiver bandwidth (dB/Hz);
- l) Earth terminal receiver transfer function (dB).

Parametric Values

The proposed measurement-system parameters are listed in Table 1. The detailed measurement procedures will be developed and described in an experiment test plan which will be prepared pending complete definition of the system parameters. In general, the tests and measurements for the experiment will be conducted as described in the following section.

Table 1
System Parameters.

Satellite transmit power (4 GHz)	0 dBw
Satellite transmit antenna (45%)—30' dish	48 dB
Satellite EIRP	48 dBw
Satellite bandwidth (500 MHz)	87 dB/Hz
Ground station antenna gain (4 GHz)—85' dish	58 dB
Ground station receiver noise temperature (50°K)	17 dB/°K
Ground station receiver G/T	41 dB/°K
Satellite receiver antenna gain (30' dia., 6 GHz, 45%)	51 dB
Satellite receiver noise temperature (1000°K)	30 dB°K
Satellite receiver G/T	21 dB/°K

TESTS AND MEASUREMENTS PLAN

Uplink Tests and Measurements

Following the establishment of the ATS F satellite "on station," a series of diagnostic tests will be performed to calibrate the antenna system, including patterns, axes orientation, attitude stability, and orbital position. Additional measurements will be made to determine overall system performance, including transmit-receive gain, polarization, pointing accuracy, noise temperature,

and EIRP of both the satellite and ground terminals. With the earth terminal configured in a back-to-back loop through the satellite and transmitting up at 6 GHz and receiving at 4 GHz, the overall noise performance of a simulated satellite communications system will be measured. The simulated system will represent a fully loaded system with 60 to 1200 channels of FDM/FM multiplexed voice signals. Noise loading will be used to simulate the voice signals. Noise power ratio measurements will be made in selected voice channels across the baseband. All of these n.p.r. measurements (which will be used for comparison with the experimental measurements) will be made using the earth coverage (low gain) antenna of the satellite, and with the main beam of the high gain (30-foot) antenna pointed to a "quiet spot" on the earth. Similarly, using the same configuration, reference data will be established from measurements of the system carrier-to-noise and baseband signal-to-noise ratios. Carrier frequencies for the simulated system will be variable to allow calibrations in regions of the allotted common carrier band where interference is most likely to occur. Then the main beam of the high gain antenna will be pointed toward a high density population area such as the northeastern coastal region of the United States. The satellite receiver terminals will be parallel coupled to both high and low gain antennas while the transponder output (transmitter) terminal will remain connected only to the low gain antenna for transmission at 4 GHz to the tests and measurements earth terminal. The earth terminal remains in the simulated back-to-back loop configuration. Thus the measurement system now contains both the simulated desired signals (and basic noise) plus the real (unwanted) noise signals from all earth sources within the field of view of both satellite antennas. These unwanted noise signals, sharing the same common carrier frequency as the simulated system, can now be determined by remeasuring the system n.p.r. and carrier-to-noise (C/N) and baseband signal-to-noise (S/N) ratios.

The procedures described above for the uplink interference measurements will be repeated for different areas to determine the geographical distribution of interference sources. The sweep-frequency receiver technique described earlier will be used to determine the frequency distribution of interference sources across the 500-MHz bandwidth of the common carrier band. Statistical time variations of noise will be determined by selecting and adjusting the duration and time of day, week, and season of interference measurements.

Downlink Tests and Measurements

For the downlink interference measurements, a small "roving" earth terminal will be required in addition to the large fixed terminal to be used for the uplink measurements. This small terminal will be similar to a typical microwave repeater terminal configured as a mobile unit to permit locating it within the main beam of the large antenna of ATS F as various geographical test areas are chosen. Special features of this small terminal will include an az-el antenna mount with RF polarization diversity, and a 500-MHz receiver with a frequency-sweeping local oscillator. The antenna mount is required to make interference measurements as a function of look angle and RF polarization relative to the satellite antenna beam. The sweep-frequency receiver is required to make interference measurements across the shared frequency band and will be identical with the one at the large earth terminal.

This small earth terminal will operate in a "receive only" mode at 4 GHz. Measurements will be made of n.p.r., C/N, and S/N while the large earth terminal is transmitting test signals at various levels and with variable carriers. At the satellite, the receiver terminals will be connected to the low gain (earth coverage) antenna and the transmitter will be connected to the high gain (30-foot) antenna. Comparative data will be obtained by making all measurements while the large earth terminal is both "ON" and "OFF." Statistical data will be obtained in the same manner as described for the uplink measurements. As depicted in the functional diagrams, Figures 5 and 6, the small earth terminal requires a 6-GHz transmitter to send calibration signals and a tracking beacon to the satellite, and a 500-MHz sweeping receiver identical to the ones in the fixed terminals. If desired, the addition of appropriate modulation and demodulation equipment would allow the small earth terminal to be used for conducting communications experiments with the ATS F satellite (see Reference 6).

SPACECRAFT TRANSPONDER REQUIREMENTS

The interference measurements repeater proposed for ATS F consists of four subsystems: 1) a low noise preamplifier, 2) redundant wideband frequency transponders, 3) redundant transmitters, and 4) RF transmission lines, couplers, mixers, and switches. In addition to the 30-foot parabolic antenna, a low gain, wide-beam transmit-receive antenna is required as shown in Figures 5 and 6. The pertinent characteristics of these subsystems are listed in Table 2.

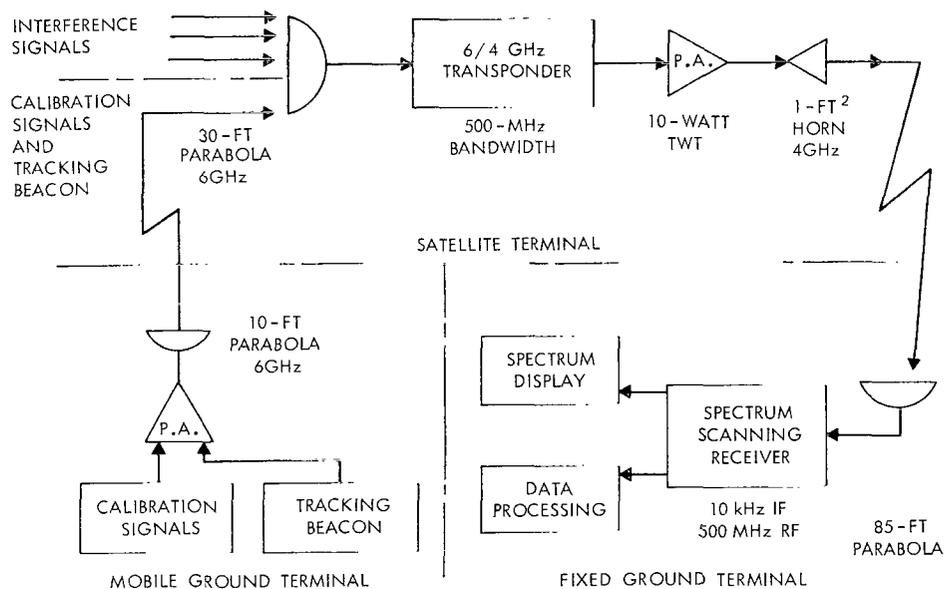


Figure 5—Uplink experiment functional diagram.

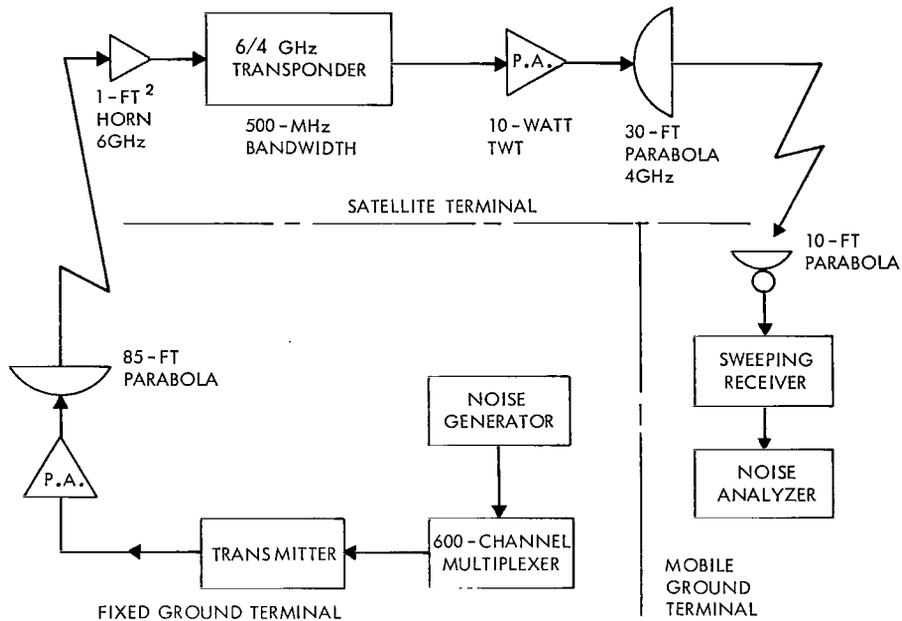


Figure 6-Downlink experiment functional diagram.

Table 2

Transponder Characteristics.

Transmitter type	Traveling-wave tube
Transmitter power output	1 watt
Transmitter Frequency	3950 ±250 MHz
Receiver type	Linear, single conversion
Receiver noise figure	5.0 dB
Receiver frequency	6175 ±250 MHz
Receiver dynamic range	40 dB
Polarization diversity	Horizontal, vertical, or circular
Volume estimate	1 cubic foot
Weight estimate	30 pounds
Prime power required	60 watts
Telemetry and command	20 digital and 12 analog channels 20 commands

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